# The Effect of the Tides on the LIGO Interferometers

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The LIGO interferometers [1] can record the dark port signal at a sampling rate as high as 262.144 kHz. Of interest is the region around the 1st free spectral range (fsr) of the 4 km interferometers, $f_{fsr} = c/2L = 37.52$ kHz. The dominant optical field in the interferometer, $E_0$, is at the carrier frequency $f_0$ and has narrow width $\Delta f_0 \sim 1-2$ Hz. In addition in the interferometer circulate sideband fields $E_{\pm}(f)$ centered at $f_{\pm} = f_0 \pm f_{fsr}$. The sideband fields have width typical of the arm cavity resonance, $\Delta f_{\pm} \sim 200$ Hz, and peak amplitude density $E_{\pm}(f) \sim 10^{-7} E_0/\sqrt{\text{Hz}}$. When the interferometer is locked, the field $E_0$ is on a dark fringe, and at the antisymmetric port (AS), the phase shift at the carrier frequency, $\Delta\phi_0 = 0$. However this does not hold for the sideband fields $E_{\pm}(f)$ because the lengths $L_x$ and $L_y$ of the two arms are not equal. Instead the phase shift at frequency $f_{\pm} = f_0 \pm f_{fsr}$ is finite and given by $\Delta\phi_{\pm} = \pm 2\pi(L_x - L_y)/L$, where $L_x - L_y \sim 2$ cm. The fields $E_{\pm}(f)$ are mixed with the radio frequency sidebands, and the photocurrent is demodulated in the usual way. This gives rise to a signal centered at $f_{fsr}$ and of amplitude density $h(f)$ proportional to the phase shift $\Delta\phi_{\pm}$ and the field density $E_{\pm}(f)$, $h(f) = C|\Delta\phi_{\pm}||E_{\pm}(f)|$. The uncalibrated frequency spectrum in counts/$\sqrt{\text{Hz}}$ , in the region of the fsr frequency is shown in Fig.1. The enhancement follows the spectral shape of $E_{\pm}(f)$.

The data are available as a time series sampled at 1024 Hz and restricted to the frequency range $37,504 \pm 1024$ Hz. The data are from the S5 science run and were written in 64 s long frames. For each frame we obtain the frequency spectrum at a resolution BW = 0.125 Hz and integrate the power spectral density (PSD) in the region $f_{fsr} \pm 200$ Hz. A filter proportional to the interferometer transfer function at the fsr is applied. This gives a time series of the power at the fsr, sampled every 64 s. The amplitude of this signal is proportional to the sum of the "biasing" phase shift $\Delta\phi_{\pm}$ given above, and of any time-dependent phase shift $\Delta\phi_t$ at the sideband frequencies $f_{\pm}$. Thus the observed (integrated) power is

$$P = \int (\text{PSD})df = \left\{(\Delta\phi_{\pm})^2 + 2\Delta\phi_{\pm}\Delta\phi_t + (\Delta\phi_t)^2\right\}|C|^2 \int |E_{\pm}(f)|^2 df \qquad (1)$$

Since $\Delta\phi_t$ is less than few percent of $\Delta\phi_{\pm}$, the last term is negligible and the time-dependent modulation of the power is

$$\Delta P/P = 2|\Delta\phi_t|/|\Delta\phi_{\pm}| \qquad (2)$$

Measurement of $\Delta P$ combined with a knowledge of $\Delta\phi_{\pm}$, (i.e. of $\Delta L$), suffices to obtain $\Delta\phi_t$.

A plot of the power for a 16 month period (April 2006 to August 2007) for the Hanford H1 interferometer is shown in Fig.2. The modulation at the daily and twice daily frequencies is clearly

seen in the inset. The 16-month time series was spectrally analyzed and contains the tidal frequencies as shown in Figs 3(a,b). To within the measurement resolution of $\Delta f_{res} = 6 \times 10^{-9}$ Hz there is exact agreement between the measured and expected values. The modulation of the power is shown as a function of time for a five day period in December 2006 in Fig.4a, and for April 2007 in Fig.4b. The blue curves give the relative amplitude of the horizontal component of the tidal forces at the Hanford site for the same time period.

# References


[1] B.Abbott et al. Nucl. Instrum. Methods, A**517** 154 (2004).


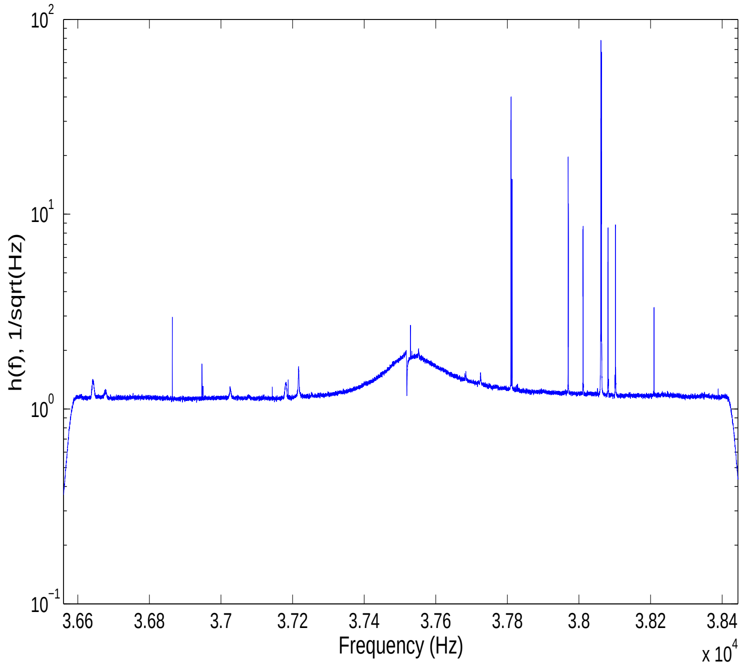


Figure 1: Uncalibrated amplitude spectral density for the H1 interferometer in the region of its free spectral range.

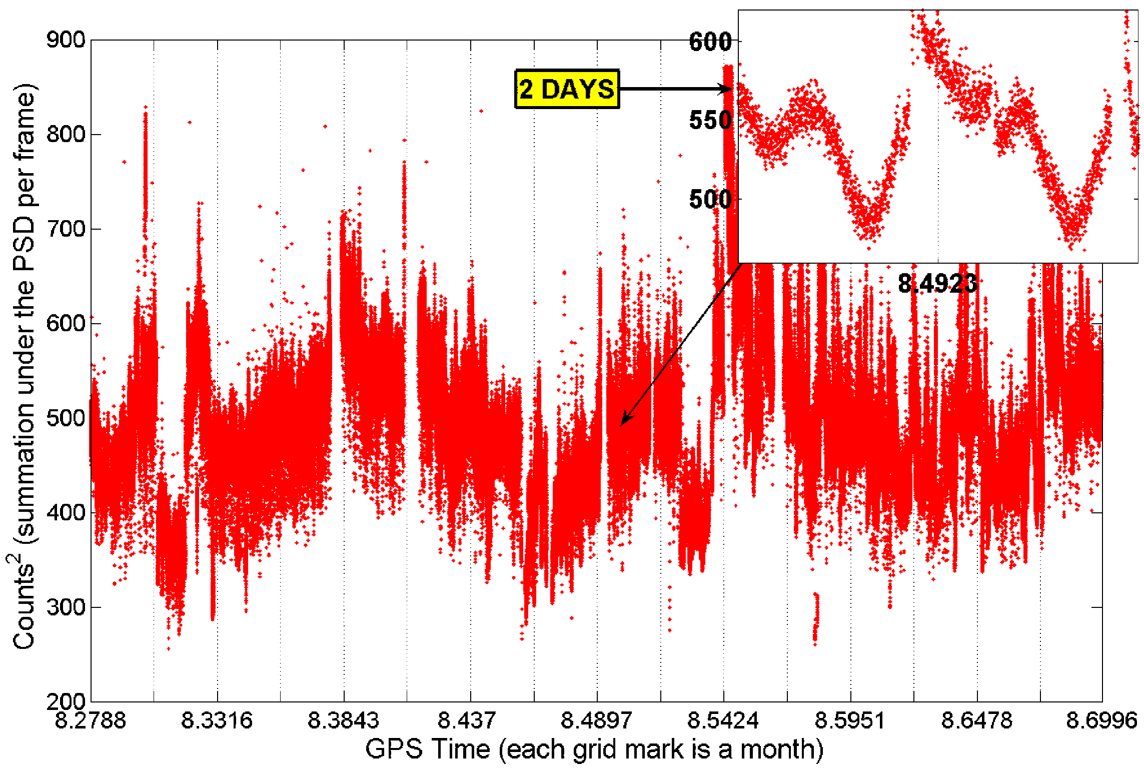


Figure 2: Integrated power in the free spectral range (fsr) region as a function of time, April 2006 to July 2007. The data are for the H1 interferometer and are sampled every 64 s. Note the daily and twice-daily modulation that can be seen in the inset.

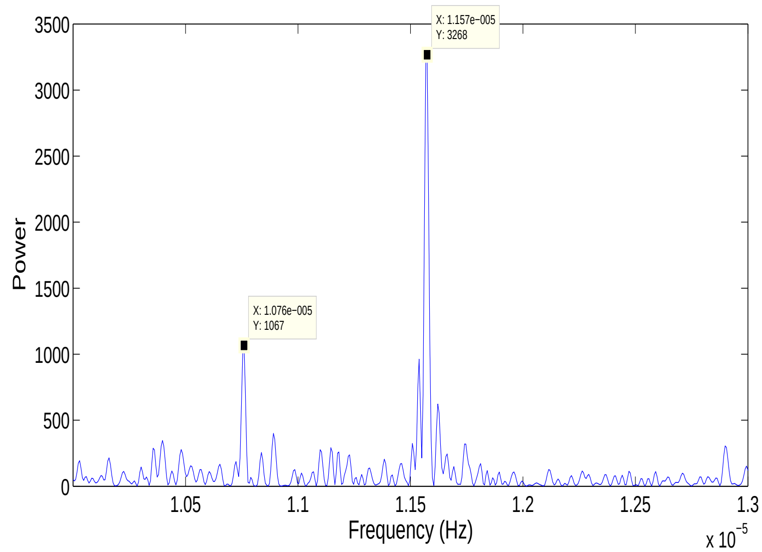


Figure 3: Frequency spectrum of the integrated fsr power in the diurnal region. Note the fine structure.

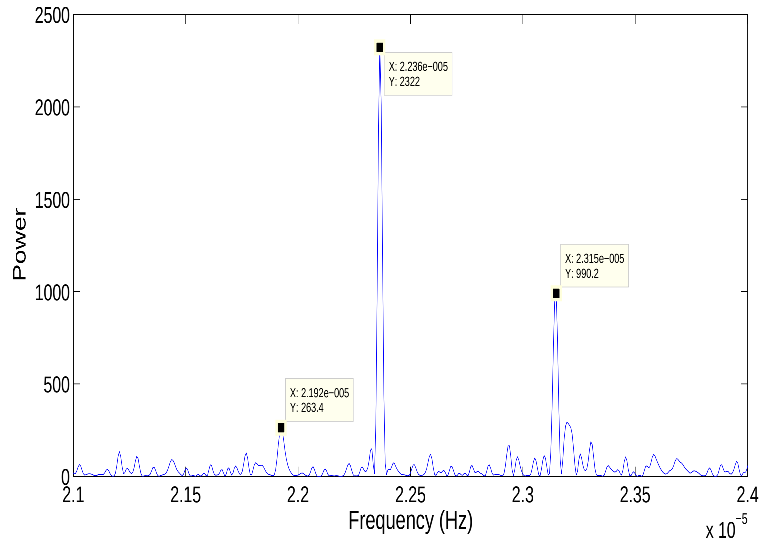


Figure 4: Frequency spectrum of the integrated fsr power in the twice daily region. Note the fine structure.

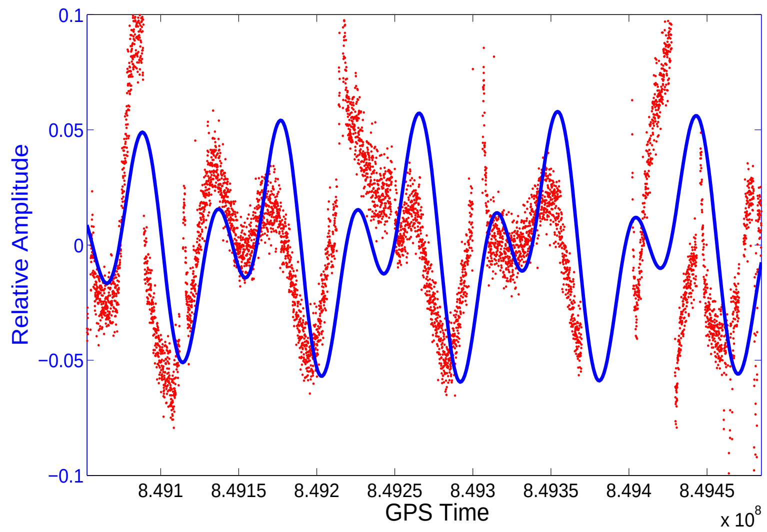


Figure 5: Modulation of the integrated fsr power for five days in December 2006. The blue curves give the relative amplitude of the horizontal component of the tidal forces at the Hanford site for the same time period.

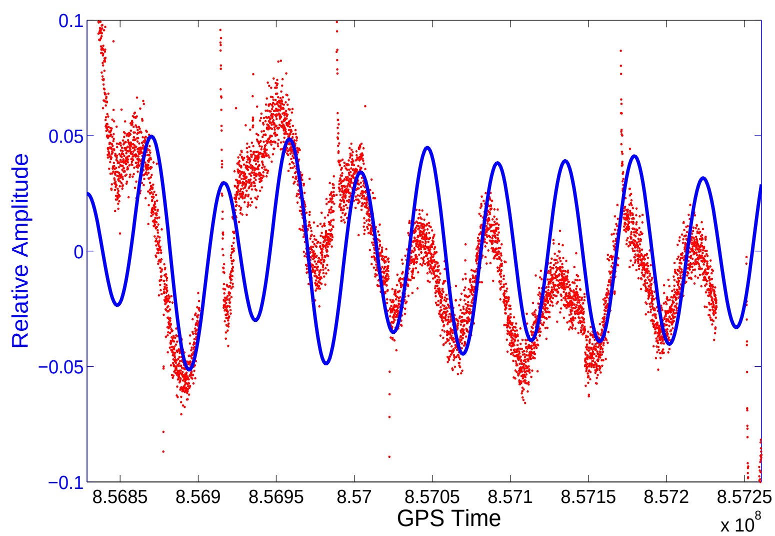


Figure 6: Modulation of the integrated fsr power for five days in March 2007. The blue curves give the relative amplitude of the horizontal component of the tidal forces at the Hanford site for the same time period.